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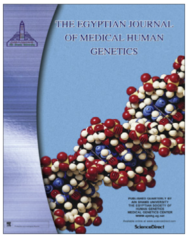

ORIGINAL ARTICLE

Effect of whole-body vibration on muscle strength, spasticity, and motor performance in spastic diplegic cerebral palsy children

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KEYWORDS

Whole body vibration;
Cerebral palsy;
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Walking balance;
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Abstract *Background and purpose:* Spastic diplegia is a common form of cerebral palsy (CP) and is characterized by spasticity and muscle weakness of both lower limbs resulting in decreased walking ability. The purpose of this study was to evaluate the effect of whole body vibration (WBV) training on muscle strength, spasticity, and motor performance in spastic diplegic cerebral palsy children after 12-weeks treatment.

Methods: Thirty spastic diplegic CP children (8–12 years) were randomized to two equal groups, control group and WBV group. The control group received a selected physical therapy treatment program for spastic diplegic CP and the WBV group received the same program in addition to WBV training. Measurements of isometric strength of knee extensors, spasticity, walking speed, walking balance and gross motor function were performed before and after 12 weeks of the treatment program.

Results: Isometric strength of knee extensors, spasticity and the walking speed were significantly improved only in the WBV group ($P < 0.05$). Growth motor function measure-88 (GMFM-88) (D%) was significantly increased ($P < 0.05$) in both groups in favor of the WBV group and GMFM-88 (E%) was significantly increased ($P < 0.05$) only in the WBV group, while walking balance did not change significantly in either group.

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Conclusion: The obtained results suggest that 12-weeks' intervention of whole-body vibration training can increase knee extensors strength and decrease spasticity with beneficial effects on walking speed and motor development in spastic diplegic CP children.

1. Introduction

CP is a syndrome characterized by poor control of movement and posture, which appears early in life and is considered as the most common cause for children handicapping representing nearly 2 per 1000 live births [1]. The most common form of CP is spastic diplegia and in this form both legs are more involved than the arms so that walking ability is affected [2]. The imbalance of muscle strength and tone causes muscle weakness and atrophy over time, as well as soft tissue contracture and eventual joint deformity. Children with spastic diplegia usually walk independently but most have gait disorder that is known as spastic diplegic gait which includes walking with plantar flexed feet, flexed hips and knees and an anteriorly tilted pelvis with exaggerated lumbar lordosis .This gait disorder makes them walk at a decreased speed with high energy expenditure and restricted functional capability when compared with their healthy peers [3–7].

Improving the ability to walk or perform other functional activities is often the primary therapeutic goal for spastic diplegic children [8]. Adaptive equipment that try to compensate for reduced mobility consume a large proportion of the costs related to CP [9], thus measures that improve mobility in children with CP could potentially result in substantial savings for health care systems.

Muscle strengthening is an important method to train weak muscles responsible for impaired walking ability like quadriceps muscle in spastic diplegic children. WBV is now a rapidly developing method used to increase muscle strength in clinical conditions [10–12]. It is a neuromuscular training method that was initially used by elite athletes to improve both speed and strength. Several reports state that WBV can have a beneficial effect on strength and power, however, there is a lack of scientific researches supporting the benefits of WBV on fitness and health [13,14]. In WBV training, the subject stands on a platform that produces vertical vibrations which stimulate the muscle spindles resulting in reflexive muscle contraction [15].

In adults with spastic diplegic CP, WBV has been shown to improve muscle strength and reduce spasticity of the knee extensor muscles [16]. Also, in individuals with multiple sclerosis, WBV has been associated with improvements in knee muscle performance [17]. Bosco et al. [18,19] found an increase in force power, velocity and jump performance immediately after one session of WBV training. Another study showed that WBV improves isometric strength of the quadriceps muscle and vertical-jump performance [20].

Cardinale et al. [21] suggested that vibration is effective in enhancing strength and the power capacity of humans. Also, it was suggested that WBV training resulted in neuromuscular adaptations similar to the effect produced by strength training [22].

The aim of this study was to evaluate the effect of WBV training on muscle strength, spasticity, walking speed, walking balance, and gross motor ability after 12 weeks in spastic diplegic CP children.

2. Subjects and methods

2.1. Subjects

Thirty spastic diplegic CP children of both sexes with ages ranging from 8 to 12 years (9.63 ± 1.41 years), who are able to walk with or without walking aids with an abnormal pattern of gait, who can understand or follow instructions, with a degree of spasticity ranging from 1 to 2 according to the modified Ashworth scale [23] not being engaged in regular organized physical activities were included. The exclusion criteria include children with fixed musculoskeletal deformities, with a history of recent surgery (less than 1 year) or unhealed fractures, who were medically unstable as determined by history and medical records, any case of epilepsy or visual or auditory problems and those under treatment with botulinum toxin. These children were selected from the outpatient clinic, college of Physical therapy, Cairo University. They were equally randomized to intervention with either control group or WBV training group. This work is carried out in accordance with the code of Ethics of the World Medical Association (Declaration of Helsinki) for experiments involving humans. Parents of the children signed a consent form prior to participation as well as acceptance of the Ethics Committee of the University.

2.2. Materials

2.2.1. For evaluation

2.2.1.1. Handheld dynamometer. Nicholas Manual Muscle Tester, Model 01160; Lafayette Instrument, Lafayette, IN, a commercial device was used to assess isometric knee extensor muscle strength. Hand-held dynamometers have been shown to be reliable instruments for measuring knee extension strength [22], and they have been used successfully in measuring muscle strength in children with spastic diplegia [24].

2.2.2. For treatment

2.2.2.1. Whole body vibration. A commercially available device (Power Plate; Northbrook, IL) with a side-alternating vibration platform, which generates vibration by allowing separate and unsynchronized multidimensional oscillations along the sagittal axis was used. In this study the device was set to produce a peak- to peak-sinusoidal vibration with an amplitude ranging from 2 to 6 mm. There were three positions illustrated on its platform marked as "1", "2", "3" corresponding to peak-to- peak displacements of 2 mm, 4 mm, and 6 mm. The vibration frequency ranged from 12 to 18 Hz for the aim to prevent adaptations of the neuromuscular system. In addition, these stimuli cannot generate resonance catastrophes or kinesthetic illusions [25].

2.3. Methods

2.3.1. For evaluation

All the tests were performed before and after the 12-week treatment period.

2.3.1.1. Strength. Isometric strength of knee extensors, in Newton (N) was assessed using a handheld dynamometer. The children were seated in sitting position with their knees flexed at 90° and resistance was given by the examiner anteriorly 5 cm proximal to lateral malleolus. The examiner gradually applied force over one second to allow the child to adjust and recruit a maximum number of muscle fibers. Three attempts at each muscle group were recorded. The first attempt was used for familiarization and a score was obtained by averaging the second and third attempts.

2.3.1.2. Spasticity. Spasticity of hip adductors, knee extensors, and ankle plantar flexors was evaluated according to the modified Ashworth scale, which has 6 degrees (0, 1, 1+, 2, 3, and 4). The reliability of the modified Ashworth scale has been considered good [23], but the validity has been shown to be insufficient to be used as a 6-point ordinal scale to measure spasticity [26].

2.3.1.3. Walking speed. Walking speed was tested using the 6-min walking test (6MWT). One practice session was performed some days before the actual test, to reduce the effect of learning. The participants were instructed to walk back and forth in a hallway as far as possible for 6 min. Instructions and comments during the test were standardized using guidelines from the American Thoracic Society [27–30].

2.3.1.4. Walking balance. Balance in basic mobility maneuvers was tested with the Timed Up and Go test (TUG). The participants sat on a standard armchair and were instructed to get up and walk in a comfortable and safe pace to a line on the floor 3 meters away, turn around, return to the chair and sit down again. The time required to complete the task was recorded. One practice session was performed once before the actual test. Intra-rater reliability of TUG test in cerebral palsy children was found to be high [31].

2.3.1.5. Gross motor function. The gross motor performance was tested with GMFM-88 [32]. It consists of 88 items within 5 dimensions: (A) lying and rolling; (B) sitting; (C) crawling and kneeling; (D) standing; (E) walking, running and jumping. The items are scored using a 4-point scale (0, 1, 2, and 3) and the scores are presented in percentages, and in this study only dimensions D and E were assessed. The reliability and validity of the GMFM has been shown to be good in children with CP [33].

2.3.2. For treatment

Children of both groups received a selected physical therapy program. Each session was conducted for 1 h, three times per week and for three successive months, including:

- Stretching exercises for Achilles tendon, hamstrings, hip flexors and adductors of both lower limbs, upper abdominal and pectoralis muscles.
- Strengthening exercises for scapular retractors, spinal extensors, lower abdominal, hip and knee extensors, and dorsiflexor muscles.
- Facilitation of postural reactions, including: facilitation of righting, equilibrium and protective reactions from sitting on ball.
- Facilitation of standing and weight shift.
- Facilitation of standing balance by tilting the child from standing to different directions (forward, backward and side-way) using a balance board.
- Gait training: by forward, backward, and side-way walking between parallel bars (closed environment gait training), and open gait training was also conducted.

In addition to the selected physical therapy program, WBV group received WBV that was administered for 3 series lasting for 3 min, followed by 3-min pause between each series, thus each session consisted of 9 min exposure to WBV. The patient stood with shoes and with the knees slightly bent, and feet are placed at equal distance from the center of the platform allowing separate and unsynchronized multidimensional WBV applied to both feet. The first session started with a vibration frequency of 12 Hz, and 4 mm peak-to-peak amplitude aiming to increase the frequency and amplitude to be 18 Hz and 6 mm peak-to-peak amplitude as indicated by previous studies [25].

For some children who had problems in standing with equal weight-bearing on both feet, or those with feet which could slide off the vibration platform, there was a person who was supervising them and ready to stabilize them if that was about to happen. During all of the vibration-training sessions, the children wore the gymnastic shoes to standardize the damping of the vibration due to footwear.

3. Statistical analysis

The mean values of isometric strength, spasticity, walking speed and balance, and motor development obtained before and after 12-weeks treatment in both groups were compared by using the Statistical Package for the Social Sciences (**SPSS**) version (16) using the paired "*t*-test", and an independent "*t*-test" was used for comparison between two groups. The results were expressed as mean ± SD, and P values less than 0.05 were considered significant.

4. Results

There were no significant differences in any of the presented variables between the control group and the WBV group before the intervention period. All participants were present in at least 85% of the 36 training sessions.

4.1. Strength

Mean values and standard deviations of knee extensors strength in both strong and weak legs before and after 12-weeks treatment in both control and WBV groups are presented in Table 1. There was a significant increase in the knee extensors comparing the pre and post treatment results of both weak and strong legs in the WBV group ($P < 0.05$), but in the control group there were no significant changes. Also there was a significant difference comparing the post treatment mean values between both groups in the weak legs only, while there was no significant change in strength between the strong legs.

4.2. Spasticity

Mean values and standard deviations of spasticity in both strong and weak legs before and after 12-weeks treatment in both control and WBV groups are presented in Table 2. Of the 3 tested muscle groups there was a significant reduction of spasticity in the knee extensors of the stronger leg in the WBV group ($P < 0.05$). In the control group there were no significant changes.

4.3. 6-Min walk test

Mean values and standard deviations for 6MWT before and after 12-weeks treatment in both control and WBV groups are presented in Table 3. Mean values for 6MWT were significantly changed in the WBV group after treatment ($P < 0.05$) compared to the pre-treatment values. Also there was a significant difference comparing the post treatment results in favor of the WBV group ($P < 0.05$).

4.4. Timed Up and Go test

Mean values and standard deviations for TUG before and after 12-weeks treatment in both control and WBV groups are presented in Table 3. Mean values for TUG were not changed significantly in any group after treatment ($P > 0.05$).

4.5. Gross motor function measure

Mean values and standard deviations for the GMFM before and after 12-weeks treatment in both control and WBV groups are presented in Table 4. The total values for dimension (D%) were significantly increased in both control and WBV groups after treatment ($P > 0.05$) and when comparing the post treatment values there was no significant difference in the treatment effect between both groups ($P > 0.05$), while the total values for dimension (E%) were significantly increased comparing the pre and post treatment values in the WBV group ($P < 0.05$) and there was no significant change in the values after treatment in the control group. When comparing the post treatment values there was a significant difference in the treatment effect between both groups ($P < 0.05$) in favor of the WBV group.

5. Discussion

There has been limited research on the effects of WBV exercise in treatment of cerebral palsy children. The aim of this study was to compare changes in strength, spasticity, walking speed and balance and gross motor function after 12 weeks of intervention with WBV and we observed that WBV was feasible and appeared to be safe in children with spastic diplegia. Based on the subjective reports, WBV was well tolerated by all the patients without reporting immediate or delayed adverse effects such as dizziness, kinesthetic illusions, discomfort, or pain, except for redness of the feet or ankle area, which was observed in 80% of patients after first treatment sessions and which is a well-known reaction to WBV.

In the present study, the results reveal significant improvement in isometric knee extensors strength of the WBV group which comes in agreement with the results of Delecluse et al. [34] who concluded that WBV can produce reflexive muscle contraction and an increase of strength of knee extensors in previously untrained females to the same extent as resistance training at moderate intensity. Another study showed an increase in both concentric and eccentric work and eccentric peak torque in the WBV group's weaker leg of adults with cerebral palsy [16]. Bosco et al. [35] reported the effect of a 10-day training program of a daily of vertical sinusoidal vibrations at a frequency of 26 Hz. They found a significant improvement in the jumping performance. Also, it was suggested that WBV training resulted in neuromuscular adaptations similar to the effect produced by strength training [36].

It is well known that the input of proprioceptive pathways is used in the production of force during isometric contractions [37]. By using WBV, the vibratory stimulus is highly activating the deep sensory receptors and their pathways resulting in reflexive muscle contractions. The increase in isometric strength after 12 weeks of intervention of deep sensory stimulation may result from an efficient facilitation of the positive proprioceptive feedback loop in the generation of isometric force.

There is a significant decrease in knee extensors spasticity after treatment, while the results of the other evaluated muscle groups show no significant difference in spasticity. The same findings were obtained after 8 weeks of WBV intervention in fourteen adults with spastic diplegia [16].

Table 1 Mean values and significance of knee extensors strength in Newton (N) in both groups for weak and strong legs before and after treatment.

Leg	Control group				WBV group				Post control Vs Post WBV	
	Weak		Strong		Weak		Strong		Weak	Strong
Values	Pre	Post	Pre	Post	Pre	Post	Pre	Post		
Mean (N)	24.667	25.333	23.333	24.00	25.00	28.00	24.00	27.00		
SD	±0.764	±0.289	±1.258	±0.500	±0.866	±1.000	±0.866	±1.00		
t-Test	−4.00		−2.65		−10.39		−8.66		4.00	3.87
P-Value	0.057		0.118		0.009		0.013		0.028	0.61
Sig.	NS		NS		S		S		S	NS

SD: standard deviation; P value: level of significance; Sig.: significance; S: significant; NS: not significant.

Table 2 Mean values and significance of spasticity estimated with modified Ashworth scale (0, 1, 1+, 2, 3, 4) in both groups for weak and strong legs before and after treatment.

	Group	Control group		WBV group		Post control Vs Post WBV
	Values	Pre	Post	Pre	Post	
Knee extensors (weaker leg)	Mean	1.833	1.333	2.667	1.167	
	SD	±1.041	±0.577	±0.577	±0.289	
	t-Test	1.73		5.2		0.45
	P-Value	0.225		0.035		0.698
	Sig.	NS		S		NS
Hip adductors (weaker leg)	Mean	2.167	1.667	2.667	1.333	
	SD	±0.764	±0.289	±0.577	±0.289	
	t-Test	1.73		3.02		1.41
	P-Value	0.225		0.094		0.230
	Sig.	NS		NS		NS
Ankle plantar flexors (weaker leg)	Mean	1.833	1.667	2.667	1.667	
	SD	±1.041	±0.289	±0.577	±0.289	
	t-Test	0.38		3.46		0.00
	P-Value	0.742		0.074		1.00
	Sig.	NS		NS		NS
Knee extensors (stronger leg)	Mean	1.333	1.167	1.833	1.500	
	SD	±0.577	±0.289	±0.289	±0.500	
	t-Test	1.00		2.00		−1.00
	P-Value	0.423		0.184		0.391
	Sig.	NS		NS		NS
Hip adductors (stronger leg)	Mean	1.833	1.500	1.833	1.500	
	SD	±0.289	±0.500	±0.289	±0.500	
	t-Test	2.00		2.00		0.00
	P-Value	0.184		0.184		1.00
	Sig.	NS		NS		NS
Ankle plantar flexors (stronger leg)	Mean	1.500	1.333	2.00	1.833	
	SD	±0.500	±0.289	±0.00	±0.289	
	t-Test	1.00		1.00		−2.12
	P-Value	0.423		0.423		0.101
	Sig.	NS		NS		NS

SD: standard deviation; P value: level of significance; Sig.: significance; S: significant; NS: not significant.

Table 3 Mean values and significance of walking speed (m) and walking balance (s) in both groups before and after treatment.

		Control group		WBV group		Post control Vs Post WBV
		Pre	Post	Pre	Post	
6 MWT (m)	Mean	203.3	221.7	240	400	
	SD	±33.3	±46.5	±60	±50	
	t-Test	−2.08		−27.71		−4.53
	P-Value	0.173		0.001		0.020
	Sig.	NS		S		S
TUG (s)	Mean	51.67	48.67	53.33	51	
	SD	±7.64	±6.03	±12.58	±10.15	
	t-Test	3.00		1.61		−0.34
	P-Value	0.095		0.250		0.755
	Sig.	NS		NS		NS

SD: standard deviation; P value: level of significance; Sig: significance; S: significant; NS: not significant.

In individuals with upper motor neuron lesions, there are multiple consequences of poor communication between the brain and spinal cord resulting in loss of descending modulation of the spinal reflex arc which in turn results in spastic hypertonia with reflex hyper excitability and loss of motor control (i.e. spastic gait patterns). Peripheral sensory input via localized vibratory stimulation applied to specific muscles may activate the modulatory systems that produce modulatory effects similar to those of the descending pathways. Individuals with spinal cord injuries offered further evidence for the

Table 4 Mean values and significance of Growth Motor Function Measure dimensions (%) in both groups before and after treatment.

		Control group		WBV group		Post control Vs Post WBV
		Pre	Post	Pre	Post	
GMFM (D%)	Mean	73	78	71.33	86.67	
	SD	±7.2	±7.63	±10.02	±7.64	
	t-Test	−16		−5.28		−1.34
	P-Value	0.004		0.034		0.252
	Sig.	S		S		NS
GMFM (E%)	Mean	67	75.33	80	91.33	
	SD	±6.24	±5.51	±1.00	±3.21	
	t-Test	−3.05		−8.50		−4.35
	P-Value	0.093		0.014		0.022
	Sig.	NS		S		S

SD: standard deviation; P value: level of significance; Sig.: significance; S: significant; NS: not significant.

modulatory influence of vibration in reflex activity by some studies where local tendon vibration was accompanied with improved reciprocal inhibition [38–40].

The effects on motor performance in the form of speed of walking, walking balance and gross motor function were also evaluated. Walking a distance of 6 min was significantly increased in the WBV group, while the walking balance and turning did not change in any intervention group. This comes in agreement with a study where the average walking speed in the 10-min walking test was increased in patients who received vibration therapy without any change in the control group [41].

The gross motor function for dimension (D%) which is related to the standing ability increased significantly in both groups without any significant difference between both groups. For dimension (E%) which is related to the walking, running and jumping, the results were significantly increased in the WBV group only. These findings were consistent with some authors who concluded that WBV might be a good approach to improve movement ability in hemiparetic cerebral palsy children and in severely motor-impaired adults [42,43].

6. Conclusion

The data in the present study suggest that 12 weeks of intervention with WBV can increase muscle strength, walking speed, and gross motor performance related to standing and walking without any negative effects and on spasticity, while walking balance did not change significantly in any intervention group.

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